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Classification of Coasts

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ABSTRACT

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The simplest description of a given coast requires a minimum of three terms, embracing the following: (1) material (hard/soft; soluble or otherwise); (2) agencies (erosive/constructive; physical, chemical, biological, and geographic setting [latitude, exposure, fetch]), and (3) historical factors (time scale: geotectonic, glacioisostatic, eustatic, steric, anthropic). Deductive reasoning based on instrumental data such as tide gauges frequently lead to misleading conclusions, in that most are located in the northern hemisphere (land-dominated), near river mouths (variable runoff), sediment compaction, crustal lowering, coriolis effect of geostrophic current variation, and excessively short data spans (< 100 yr). Climatic oscillation influences sea level on all scales from ENSO (El Niño Southern Oscillation) and NAO (North Atlantic Oscillation) up to 1500 yr or more. Satellite observations furnish only the briefest "snap-shots."

Classifications based on perceived "relative" relationships such as *submergence* or *emergence* are useful as generalizations, but only when provided with the time scale. Similar constraints apply to *subsidence* and *uplift*, and always subject to the three fundamental criteria.

Classification has been a long and vexed problem in coastal science (see references and summary in BIRD, 2000, p.289–299). First, it must be addressed as a *multidisciplinary* undertaking, a branch of *typology* that calls for *multivariate analysis.* Secondly, the specific *user needs* must be considered: theoretical or practical. Are the readers consultant engineers or geomorphological historians? Thirdly, the *scale* is critical: continent-wide? A single coastline? Or a pocket-beach, constrained by two headlands? The use of GIS, Geographical Information Systems, is a methodology well suited to this sort of study (COOPER and MCLAUGHLIN, 1998).

Progressive coastal classification has been analogous to the histories of sedimentology and other subdisciplines of the geological or earth sciences. Initially the 19th century observers would note *descriptive characteristics,* such as cliffed, deltaic or mud-flat. This methodology was soon dismissed as simplistic and the urge was to identify some fundamental attribute relating to the origin or mode of formation.

In sedimentology, for example, a glacier is known to carry a load of pebbles and boulders while its subglacial meltwaters are loaded in addition with mud. If the glacier debouches in the ocean the nearshore sediments are "pebbly muds", destined to become "pebbly mudstones" or "tills", and then consolidated to become "tillites". However, controversy emerged when ancient conglomerates were sometimes misinterpreted and some authors suggested "tilloid" when in doubt (although the "-oid" suffix is commonly prejudicial). Another variant was "diamicton", or in lithified form "diamictite", but with most writers such terms have passed into oblivion, and the short, simple genetic term tillite is preferred. The sedimentologists usually proceed with a standard descriptive classification at the hand-specimen or microscopic level.

This analogy provides a clue as to the coastal specialist's terminologic procedure, based on SCALE. At 1–1000 m scale the simplest descriptor is appropriate. At 1–1000 km the subject demands a more sophisticated modifier.

Literature on the classification of coasts is voluminous. An excellent appendix on the subject is found in BIRD (2000), and summarized in WOODROFFE (2002, p.43 et seq.). In the FAIRBRIDGE (1968) encyclopedia it was briefly reviewed and illustrated by SHEPARD, with the classic citations to VON RICHTHOFEN (1886), SUESS (1888), JOHNSON (1919, 1925) and TANNER (1960). COTTON (1954) developed a dichotomy between "stable" and "unstable" coasts, but it had problems with scale and eustatic processes. SHEPARD (1937, 1948/73) himself had made a new approach, distinguishing coasts shaped by terrestrial agencies and those by marine action. Another genetic system was that offered by KING (1959/'74) which is excellent in that class. VALENTIN (1953) presented the first color-printed global map of genetic coastlines.

As noted above, the system of approach in this entry is descriptive, actualist, and only genetic in a modifying sense. Thus, a two or threefold basic terminology is required, with an option for tectonic and eustatic history.

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COASTAL MATERIAL

All the world's coasts are divisible into a simple bifold division: *hard* and *soft*. Engineering work on coastal erosion, or control of some sort, always has to face the question: hard or soft solution. This choice is not childish, but a critical first approximation.

(a) Soft, Weakly Consolidated, and Easily Erodable Coasts

For the soft category, a simple range of granulometry is sufficient to start with, *e.g.* micron-size clay ("mud", if wet), silt, sand, gravel, boulder. Solubility is a factor in the case of soft materials that result from abrasion of limestone, coral or broken shells (carbonate sands or breccia). The cemented product is then termed a "calcarenite", typically *beachrock* formed by low-tidal exposure to solar radiation; or "eolianite", a cemented dune rock.

Solution applies also to volcanic ejecta, glass, tephra, pumice, *etc.* (It may be noted, that after an eruption, ocean currents will carry pumice more than 1000 km, but if washed up on a beach its longevity is rather limited).

(i) Relatively insoluble, Detrital Material

Many of the world's coastlines fall into the insoluble, "muddy" category. Often this has a single explanation: pH. The bulk of rivers are acidic (low pH) and at times carry a large load of colloidal clay in suspension. However, salt water has an electrolytic effect and the clays coagulate forming mudbanks, and eventually are swept out to sea. Storms stir up the muds which return to the coastal lagoons. The classical areas are around the North Sea, notably in the Waddenzee of the Netherlands, the Wattenmeer of north Germany, and to a smaller extent, the Wash in England. All the world's great rivers generate deltaic facies where the muds and fluvial sands interfinger: the Mississippi, Amazon, Niger, Zambezi, Po, Nile, Tigris/Euphrates, Indus, Ganges/Brahmaputra/Megma, Irrawaddy, Yangtze, Huang-Ho, Fly and so on. Much of this suite eventually becomes transported (as turbidites) to deep water, but longshore currents take a certain fraction downdrift and it may then return to the coast.

The biology and climate furnish secondary characteristics for the soft, muddy coasts. Three major classes exist, two in the high rainfall belts: the *salt marshes* of the northern high to moderate latitudes; and the *mangrove* (or "mangal") forests of subtropical to equatorial latitudes (WOODROFFE, 2002). Both support a complex ecosystem, including a vigorous "infauna" of burrowing organisms. The stilt roots and pneumatophores of the various mangrove species play also a mechanical role in obstructing wave action and longshore currents. The third category is a feature of the low-rainfall subtropics, known from the Arabic name *sabkha* (or *sebkha,* favored in French-speaking countries) or playa in English. It is intertidal to supra-tidal, a flat area characterized by brine pools, evaporite mineralization, notably gypsum and proto-dolomite. Typical examples are seen in North Africa and the Persian Gulf. (The arabic terms are also applied to non-coastal playas.).

The "soft" coasts include "easily erodable" materials. Highest in this group are the sandy and gravelly coasts, as well as the poorly cemented siltstones, sandstones and mixed materials, such as the mixed products of the last (Wisconsinan) glaciation and its morainic debris. The soft coasts include also the loose products of recent volcanism, typically cinder cones and varied tephra.

A number of soft formations are interstratified with hard layers or with resistant nodules or concretions. Wave erosion commonly quarries the cliffs, so that longshore drift carries away the "fines", leaving the more resistant blocks or concretions to contribute to a cobble or boulder beach. A subovoid form of cobble is typical of marine erosion, as distinct from the approach to sphericity of the ideal cobble (a product of fluvial rolling). A classic example is the Chesil Beach in the county of Dorset on the south coast of England (BIRD, 2000). A distinctive sorting or grading is a result of uniform wave approach. At its southeastern end the top of the Chesil Beach reaches 13 m above high tide limit, *i.e.* its swash range.

Most familiar of all "soft" coasts are the sandy ones that constitute 20% of the world's coastlines. They furnish the human urge for playground activities. Seaside homes are widely constructed very close to the shore and consequently are in extremely hazardous locations due to rise of sea level, tsunamis, storm cycles and hurricanes. More than one billion people reside within about 10 km of the actual shoreline, many engaged in ancillary activities, such as service industries and fisheries (NORDSTROM, 2000).

Sand is defined as a detrital rock or mineral fragments in the size range of 1/16 to 2 mm, in the category between silt and finest gravel (WOODROFFE, 2002, p.72). The grains vary between near-sphericity to extreme angularity, the latter being termed "grit", recognizing its utility for grinding and cleaning ("sand blasting").

An intermediate category is "grus", a German term (WILHELMY, 1958; sometimes called "crumble" in English) for a residual weathering product of granite and granitic rocks, and of arkose, where the feldspars have been altered to clay, leaving quartz grains unaltered, which are a major contributor to many beach sands. TWIDALE (1968) calls it "granular disintegration". Massive boulders on a tropical beach are often a product of "grusification" which tends to work along joint planes (most accessible to ground water), gradually assuming a rounded product, a "woolsack" (German) or "tor" (U.K.). In the tropics, heavy rains often generate mudflows that carry the boulders long distances to the coast where wave action differentially removes the clays.

In composition, sand can be found in great variety. Most familiar is the almost monomineralic quartz sand found in mature deserts. However, it usually is polygenetic and the result of a complex sequence of events, involving

(a) the weathering of granitic rocks to saprolite, as emphasized by BÜDEL (1982) it is the equatorial belt that is the key to most weathering processes;

(b) uplift and physical break-up of the saprolite to become part of a fluvial bed-load;

(c) gravitational sorting in the stream-flow in progressive (seasonal) steps that deposit the denser particles and bring the lighter elements to remote sites. However, some of the denser particles are also most durable and minerals like cassiterite and placer metals (gold, silver, *etc.*) tend to segregate in stream-bed hollows;

(d) lighter minerals (notably quartz) tend to accumulate in sand bars and river banks. In the dry season these particles get picked up by the wind and may be carried (eventually) long distances. In this process quartz grains become progressively abraded and rounded;

(e) in certain high latitude or mountainous regions the erosive agent is glacial ice, in which case the chemical breakdown to saprolite is by-passed to permit the survival of sand-sized components of potentially soluble minerals such as feldspars and micas;

(f) under semi-arid climate conditions, the major allogenic rivers erode (by abrasion) bedrock of mainly igneous origin to liberate feldspars and micas into the bedload of those streams. Carried downstream to the coast, these contribute *arkosic sands.*

(g) on offshore volcanic islands the beach sands are often black, being derived from basalt flows. In contrast, the plate-margin volcanoes, that often erupt felsitic lavas, furnish the local beaches with lighter sands, but ones relatively low in quartz.

(h) In summary, the geological record shows that polygenetic coastal sands tend to become "cleaned" by multiple reworking, partly by wave action and partly by wind. Coastal dunes (NORDSTROM et al., 1990) develop world-wide, partly a result of the near-universal "sea-breeze" effect. Widespread coastal swamps help to create almost pure quartz sands that are free ("podzolized") of their polymictous "impurities", so that white coastal sandplains are a common feature World-wide (FAIRBRIDGE and FINKL, 1984).

(ii) Relatively Soluble Materials

A second major sand type is calcareous, and because of its solubility in rainwater is of great interest to paleoclimatic specialists. Solution and deposition of carbonate cements takes place as quickly as a few months but in some cases may require a change in the climate cycle (some centuries).

The most familiar carbonate sand is liable to form on tropical to subtropical coasts worldwide (TUCKER and WRIGHT, 1990). The presence of carbonate sands is dictated by water temperature (above 18–20°C), generally found in latitudes up to 50°N and S. They may be derived from foraminifera, calcareous algae, broken-up corals, mollusca and echinoid spines. Such bioclastic debris is created by wave action along all beaches in the warmer regions. To a varied degree they are mixed with terrigenous sands, mainly quartz and feldspars along continental coasts, but on offshore islands such as on atolls are up to 100% carbonates. Volcanic islands generate appropriate mixtures *e.g.* in the Canary Islands (ROTHE, 1996).

Several lithified products are found. First is *beachrock,* where the range of lithification is controlled by spring tides and monsoonal seasonality. Interstitial waters become enriched in carbonate solutions which precipitate during dry phases under solar radiation. Sea salts, primarily halite also join the cement, but here short-term residences are leached out during subsequent rainfall (REVELLE and FAIRBRIDGE, 1957; GUILCHER, 1958; HOPLEY, 1986; NUNN, 1994; WOODROFFE, 2000). Nearby organic swamps, claimed by some observers, are not involved, because beachrocks form just as well on isolated sand cays on atolls, devoid of vegetation. On the continental shores of peninsular India government licenses are issued for the cutting of building stone from last season's beachrock.

During seasons or cycles of slightly lowered sea level, the upper beaches dry out and are blown inland to form parallel dunes, or blow-outs with parabolic dunes (FAIRBRIDGE, 1968; NORDSTROM *et al.,* 1990). Where the interior terrain is flat or swampy a dune-building cycle with abundant sand and strong winds leads to the growth of crescentic dunes (as on the Persian Gulf and southeast Brazil). A cycle of heavy rains may lead to the lithification of the dunes into *eolianite,* or *eolian calcarenite,* best known from classical studies in Bermuda, the Bahamas and almost all tropical islands, as well as the mainland coasts of Florida, South Africa, India, and Australia (SAYLES, 1931; FAIRBRIDGE and TEICHERT, 1953). Eolianites containing a mix of volcanic material are seen in Hawaii, Lanzarote (Canary Is.), and other low-latitude volcanic areas.

Eolianites form the nuclei of reefs at various depths offshore, reflecting negative oscillations of sea level. A remarkable case was a beachrock dated 13,860 BP from the Great Barrier Reef at −150 m (VEEH and VEEVERS, 1970). Multiple sequences of emerged eolianites and beachrocks have been observed (and dated back several glacial cycles) in many localities. In places they may form prominent cliffs, but they are rather easily eroded.

Larger than sand-size are the beach components of gravel to boulder size (dimensions provided in WOODROFFE, 2002, p.71). These are special features of northern and subantarctic latitudes and elsewhere as a result of differential erosion that liberates concretions or hard-rock residuals.

Gravel and *Cobble* beaches are particularly prevalent in N.W. Europe and New England where periglacial or subglacial streams deliver well-rounded pebbles to the coastal belt where the outwash deposits are recycled by contemporary wave erosion. Ovoid to planar components are found exceptionally in the exposed areas of slates and schists of Paleozoic to Precambrian age (as in parts of Ireland and Scotland). Cobbles, subject to wave action on beaches, are gradually reduced to ovoid form and then called *"shingle"* (quantitatively defined by A. Cailleux, as to *flatness* L½E and *roundness index* $2r/L$, where L = length; E = thickness; l = breadth; r = least radius in principal plane: see GUILCHER, 1958, p.77). Concretions of varied size are common on the south coast of Britain and then are progressively reduced to shingle by wave action in a SW to NE gradation (KING, 1959/'72).

Boulder beaches are universal on the arctic and antarctic shores. There are several varieties (a) of local (hard-rock) outcrops liberated in the shore zone by freeze and thaw, or cryostatic action, a feature of the "strandflat" phenomenon in Norway, Svalbard, Novaya Zemlya and elsewhere (NANSEN, 1905; 1922; but with much debate: GUILCHER, 1958, p.160; KING, 1959/'72; OTVOS, in SCHWARTZ, 1982, p.799). The second variety (b) is marked by boulders of exotic origin, *e.g.*

granite in region of metamorphic or sedimentary rocks. In this case the boulders have been transported by sea ice and are most probably former erratics that were carried unknown distances by the ice floes. Beaches of this sort are known in the Canadian arctic, and on the Barents Sea coasts of Finnmark (Norway) and Kola Peninsula (Russia; photographs of them may be found in MØLLER *et al.,* 2002). In a storm the *sound* of these boulder beaches is positively deafening.

Boulders or blocks of irregular form constitute a third category that is generated by the hydraulic pressure of wave action and boulder impact on exposed coasts, mainly in the mid-latitudes where powerful westerly storm systems are the norm (DAVIES, 1980). These may become abraded by the smaller components and by landslide products. Near-spherical boulders are created as concretions and some of giant size may be liberated by differential wave action (some spectacular examples from New Zealand are illustrated in WOODROFFE, 2002, p.73).

A fourth type of boulder beach is of tropical to subtropical origin. The boulders are corestones of deep, tropical weathering (saprolite) that have been liberated and transported to the present shore, or former shores during low sea level stands. Here, under wave action they are progressively winnowed to create a "beach" of giant boulders. (A photograph of one in S.W. Australia, cemented in beachrock, is illustrated in FAIRBRIDGE and TEICHERT, 1953).

In the carbonate category, the common form is a *coral breccia* that is created during hurricanes, the broken coral building up into steep-sided ridges or "ramparts" (FAIRBRIDGE and TEICHERT, 1948). Some species of coral (of the "brain" or "negro-head" type) lend themselves to preservation as large boulders which are rolled across the reef flats during storms. The breccias are a universal feature of reefs subject to severe storm systems (HOPLEY, 1982).

(b) Hard Rock and Cliffed Coasts

Rock resistance is a relative term, relative in particular to the eroding agents (see below). That could be relative to storm-wave action in the zone of the prevailing westerlies which can provide a recognizable standard. GUILCHER (1958) completed his university thesis on the subject, after studies in N.W. France and S.W. England, reaching the conclusion that the rate of coastal retreat under contemporary conditions was immeasurably slow. Compared with the high rate of retreat of some soft-rock coasts (KING, 1959, p.311), this conclusion was quite surprising, but endorsed by experienced scholars (*e.g.* STEERS, 1953, 1964; SHEPARD, 1948/'73; KUENEN, 1950). As remarked by WOODROFFE (2002), p.153), "the processes that operate on these rocky coasts are generally too slow to observe" and must therefore be inferred, recognizing the roles of inheritance and polygenetic mechanisms over lengthy intervals of constantly changing conditions.

In tropical latitudes hard rocks are typically reduced to etchplains in interior, subaerial situations, but nearer the coast they are usually dissected into inselbergs. Their domes and "whalebacks" are notably developed in South Australia (TWIDALE, 1968), but in Western Australia, in the Recherche Archipelago (FAIRBRIDGE and SERVENTY, 1954), there are examples of drowned whale-backs in Precambrian granite-gneiss. Their smooth margins are totally unaffected by Holocene wave action (except for staining), and they plunge directly into the 150–200 m deep water of the outer continental shelf.

In another but very distinctive environment, in the borough of the Bronx of New York city, there is a public park with beach, bounded by bedrock, the extremely hard Fordham Gneiss, the surface of which is nicely striated and grooved by the glacial action of the last advance of the Laurentian ice sheet. This well-polished surface plunges below sea level, totally unmarked by contemporary intertidal abrasion.

The present writer, during worldwide searches for Holocene shore platforms (during his presidency of the INQUA Shorelines Commission, 1960–1968), reached the conclusion that such features were simply not to be found in hard-rock situations. On the other hand, in the adjacent bays, near stream mouths and related beachridge plains there was often abundant evidence. Furthermore, close observation of even massive granite shorelines sometimes disclose former sea-level markers in the form of *Balanus* and calcareous worm incrustations which are not only very precise MSL indicators, but can be dated by radiocarbon or other methods.

In the case of the arctic strandflats which are up to 70 km in width in Norway, only the most energetic erosive tool can be considered, that is a combination of ice-foot and sea-ice (storm-driven) will suffice.

Where hard-rock coasts are directly overlapped by fossiliferous and datable Late Pleistocene coastal ("raised beach") formations such as in Brittany, as well as Cornwall and Devon, there is no question but that any recent coastal retreat is excluded (GUILCHER, 1958). The bedrock there is Variscan (Hercynian) or older intrusives and crystalline metamorphics, creating a hard rock foundation that has withstood much periglacial attack during the Pleistocene and even tropical planation cycles during the Mesozoic up to the Pliocene. The highest Pliocene sea levels in this region (northern France and southern England) are in the range of 100 to 300 m above present, and these left an unmistakable imprint on the overall geomorphology in N.W. Europe south of the maximum Pleistocene glacial advances. The absence therefore of Early Pleistocene sea-level indicators in this region suggests that during this interval (over 2 Myr) there were episodes of highly amplified coastal retreat. Such episodes would most likely have been during the early stages of major cold cycles when sea-ice was forming diachronously *before* the great ice sheets with their corresponding eustatic falls (DALY, 1934, p.166). Evidence for this diachronous appearance of sea ice and their "exotic" debris together with giant erratics (including the "Black Rock" of Brighton) is seen along both sides of the English Channel at the same level as Tyrrhenian-stage (warm cycle) deposits several meters above present MSL (MANTELL, 1822; VELAIN, 1886; DUBOIS, 1923; FAIRBRIDGE, 1971; MITCHELL, 1977). This diachronism has bearing on the "strandflat" problems of Norway, and elsewhere in the Arctic with similar anomalous distributions of sea-ice activity. Corresponding to this lag phenomenon there is also the postglacial "retardation" noted by several authors, amounting to 5000–10,000 yr (FAIRBRIDGE, 1961, 1967).

A subject of much discussion is the cutting of the celebrated White Chalk Cliffs of Dover. How rapidly do they recede? And when were the British Isles isolated by the Straits of Dover from the European mainland? Towards the end of the Penultimate (Riss, Walstonian, or Illinoian) Glaciation around 150,000 yr BP, giant meltwater streams crossed northern Germany to converge with those in the North Sea area as the "Channel River", which may have been analogous to the ancestral Mississippi and early Great Lakes around 10,500 BP, south of present-day Chicago. Its age provides a minimum date for the Straits of Dover, which could well have been cut during earlier cycles. Overflow of the giant meltwater lakes was probably catastrophic because a deeply scarred trench (Hurd Deep) formed in the mid-Channel area, a scouring that may have been repeated several times in the manner of Glacial Lake Missoula in Oregon, but on a larger scale.

The question of the Channel erratics was also introduced by KELLAWAY *et al.* (1975) in an ingenious hypothesis that required an ice-tongue to have curled around the Cornwall-Devon peninsula and to head up the Channel in a reverse sense (eastwards). Although it had the virtue of drawing attention to the problem, it was rejected by most authorities (*e.g.* MITCHELL, 1977).

A 33 m marine terrace (with storm beach reaching 40 m) of the so-called "Milazzian" stage (or "Mindel/Riss" of the old terminology), was reported on the island of Jersey (MITCHELL, 1977, p.175). Other instances of older "raised beaches' have been mentioned, but earlier Pleistocene high sea-level stages are unknown in these latitudes, although well represented in the lower latitudes such as in Morocco and eastern North America. Widespread colluvium ("stratified head", U.K.; *grèze litée,* Fr.) might suggest an early periglacial removal of such loosely accumulated materials and subsequent accumulation as raised beaches.

The erosivity of chalk cliffs is also of relevance. On the southern Baltic coast in Poland and eastern Germany, frozen spray in winter is a powerful agency, causing occasional landslides which protect the cliff base from ice-foot erosion. In the English Channel no such contemporary agency is observed but rapid retreat is often assumed. Nevertheless, near the French town of Ault-Onival, an archaeologist, AGACHE (1964) discovered an acheulian (ice-age) fireplace with flint tools and mammoth teeth, located directly at the foot of chalk cliffs. It had been exposed by recent storms which had evidently removed a cover of colluvium (still preserved in places farther up the coast), but modern cliff retreat is not very active (FAIRBRIDGE, 1971).

Elsewhere, as at Dover itself, chalk cliffs are sometimes underlain by a sandy and water-saturated horizon, in turn resting on an impervious blue clay, the Cretaceous Gault formation. Inevitably landslides and even mudflows result, so that the freshness of the chalk cliff is not of marine origin.

Rotational slip is a feature of some stratified formations subject to gravitational sliding. A well-studied example at Dover provides the paradoxical effect of a rising "toe". Analogous landslides are observed farther west at Osmington in Dorset where an underlying clay is Kimmeridgian (Jurassic). A curious side effect of landsliding in bituminous shales is *spontaneous combustion,* sometimes triggered by lightning strikes, so that the cliff is constantly smoking.

Giant cliffs of hard materials, plunging far below sea level, are a feature of volcanic islands, the most remarkable example being on the NE coast of Molokai, in the Hawaiian chain. It is related to submarine landslides (MOORE *et al.,* 1989), as are many others. These slides are on the external slopes of the volcanoes, but in the case of giant calderas (*e.g.* Santorini) the cliffs fell away to the interior.

In the more equatorial latitudes of Polynesia, the present coasts are protected by barrier and fringing reefs but their "star-shaped" planforms suggest landsliding in their earlier histories and during cold cycles when there was no reef protection. The shape of atolls appears to reflect these earlier histories (STODDART, 1965); the convex sectors preserve the primary conical form, and the concave sectors suggest the landslide scars (FAIRBRIDGE, 1950). Even uplifted atolls may preserve such ancient scars, with the concave sector outlined in the coral limestone (see air picture of Minami-Daito, in FAIRBRIDGE, 1968, p.39). The most mature islands develop star shaped outlines.

In contrast to the curvilinearity of volcanic and landslide coasts there are the fault-controlled examples, where the steep slopes often plunge far below present sea level. Parts of the Red Sea and Gulf of Aqaba are marked by tectonic (taphrogenic) cliffs of extensional plate-rifting origin, thought their borders are often marked by coral reefs, ancient and modern (COLEMAN, 1993). Subducting margins on the other hand, although often cliffed, but nevertheless are rarely of highly resistant rocks.

Fossil or dead cliffs (*falaises mortes,* Fr.) are a feature of many stable or slightly uplifted coastlines in the temperate latitudes. The evidence of an inactive cliff or escarpment with an emerged strandline in front of it, and often associated with boulders or shingle, seems to be conclusive evidence of a "fossil" or "dead" cliff (GUILCHER, 1958).

In Arctic or subarctic waters, where the country rock is of resistant nature, the active agent has probably been sea ice or ice-foot (FORBES and TAYLOR, 1994). GUILCHER (1958, p.41) himself suspected this on the coast of Brittany, and FAIRBRIDGE (1971), as noted earlier, assembled evidence for a climatic lag ("retardation") which allowed a high eustatic sea level to be diachronous with a cooling climate by as much as 10,000 yr. Thus the entire English Channel is dotted with these apparently ice-borne boulders, some nestled aagainst Early Tyrrhenian fossil cliffs. As noted by GUILCHER (*op.cit.,* p.75) those "raised beaches" with associated dead cliffs are found throughout western Europe, including the Gower Peninsula of South Wales and others in Ireland. Although rocky shores (apart from volcanic ash and glacial drift) retreat slowly, this is greatly accelerated by sea-ice action of various sorts (WOODROFFE, 2002, p.130), in places the former cliffs (GUILCHER, *op.cit.,* p.76) "have often been covered with flows of solifluction or with loess". Where they are now fresh looking they may have been re-attacked by the waves. In arctic latitudes this covering is often preserved by permafrost, but in temperates latitudes old fossil cliffs are often degraded subaerially.

PHYSICAL SETTING

The physical situation for a given sector of the coast may seem obvious, but it is so often ignored or forgotten that it will do no harm to list some of these factors:

(a) Latitude, solar radiation, seasonality, weathering potential. BÜDEL (1982, p.119) points out that "the most effective relief-forming mechanisms" are extreme polar or equatorial.

(b) Climate corresponds to latitude, but also determines prevailing winds, sea ice, incidence of storms, hurricanes, monsoons and sea-spray (cliff retreat). Solar radiation is not constant, but should be counted as a major variable.

(c) Fetch, the extent of open water that can influence the wave and swell build-ups.

(d) Offshore bathymetry, also influencing the wave regime and longshore (NOT "alongshore") currents.

(e) Tides, both diurnal and seasonal, as well as 18.6 yr nodal, are extremely important in controlling platform development, beach progradation and retreat.

(f) Tsunami potential (volcanoes, submarine slides).

(g) Uniformity. Some beaches are almost constant in form and aspect for 100 km or so. Others will be constrained as "pocket beaches" between cliffed headlands, less than 1 km apart.

EROSIVE AGENCIES

Much attention has been paid to these agencies, but the technical training of the observer tends to create a serious bias. An integrated team approach is more likely to develop a balanced view. Four categories of such agencies exist: physical, chemical, biological and anthropic. Their respective importance should not be intuitively assumed, but can vary quite fundamentally from region to region, reflecting the material, physical setting, and history (see below).

(a) *Physical Agencies*
   (1) Abrasion (the "sandpaper effect");
   (2) Hydraulic pressure (wave action);
   (3) Wind and tide-driven ice floes and icebergs (carrying erratics as abrasive tools);
   (4) Ice-foot ("glaciel"), which applies cryodynamic forces.

(b) *Chemical Agencies*
   (1) Subaerial weathering preparation. Tropical weathering under hot-wet climates prepares massive rocks, especially granitic, creating saprolite, for disintegration by wave action and spray.
   (2) Carbonate Rocks are subject to solution especially in tide pools due to diurnal variations in temperature, salinity and pH, but always in association with biological agents.
   (3) Volcanic Rocks, including lapilli, ash, pumice and so on, often include shards of glass or K-feldspars that are relatively soluble in sea water, especially in the intertidal zone of variable pH.

(c) *Biological Agencies*
   (1) Mangrove and Salt-marsh Vegetation shed leaves and other organic debris that develop a peaty substrate characterized by very low pH and may then create "mud pools" in coral reefs and beachrocks.
   (2) An intertidal undercut in limestone or uplifted coral coasts is created by a combination of biological agents, including boring blue-green algae, gastropoda, echinoids and crabs.
   (3) Barnacles, which are very distinctive tide-level indicators, fix themselves to the rock surfaces by partly dissolving a slight depression.
   (4) Echinoids and boring molluscs (*Lithophagus* spp) mechanically scour deep hollows or tubes into massive intertidal limestone.
   (5) Kelp and other large algae anchor themselves to the rocky foreshore (holdfasts), but under storm conditions may pull out and carry rocks away.

HISTORY: GEOTECTONIC AND EUSTATIC

Interplay between these two fundamental processes is one of the pervading problems in the nomenclature of coasts. Even before the discovery of plate tectonics, two fundamental geotectonic categories were recognized by SUESS (in 1888 vol. of 1885 ser.):

- *Atlantic-type Coasts,* where pre-existing orogenic belts are transected by the present coastal trend; and
- *Pacific-type Coasts,* where the coastline runs parallel to the orogenic belts. In the "back-arc basins" and other intermediate seas of the East and West Indies, and the western borders of the Pacific and Indian Oceans, there are mixtures and intermediate sectors (see discussion in FAIRBRIDGE, 1968). These gross forms are unsatisfactory from many points of view and only used now in a generalized sense.

The plate-tectonic paradigm of the 1970's introduced a new geotectonic terminology that recognized the structural history of approximately the last 10^5 to 10^8 yr. INMAN and NORDSTROM (1971) proposed that this should be employed as a general basis for coastal classification. It is unsatisfactory, however, for terminological purposes in that its assumptions, however well justified, are inappropriate in time and scale to the coastal regime (WOODROFFE, 2002, p.46). Nevertheless, it is useful to consider the record:

(a) Passive, Extensional, Trailing-Edge, or Pull-apart Plate Margins. It is a pity that the founders of plate tectonics did not include any classical scholars, or they might have conceived a simple, unique name that would be internationally acceptable. "Extensional" seems to be the nearest approach, with "transtensional" where a strike-slip is involved. The French use these terms (MICHEL *et al.,* 1997).

The simplest and actualistic model is the Red Sea with its northerly prong, the Gulf of Aqaba (Eilat), part of a transform fault system that leads to the Dead Sea, Jordan and eventually to the edge of Anatolia. At its south end after the Strait of Bab-el-Mandeb, it joins the Gulf of Aden which is a transtensional depression. Complex taphrogenesis began in the Miocene and accelerated in the early Pleistocene, but at the present time is almost inactive. The coasts, however, do not directly reflect these dynamics but rather the eustatic history, superimposed on the normal faulting.

The South Atlantic is the simplest "pull-apart" which began about 100 Myr ago, in mid-Cretaceous time. As it passed through a "Red Sea" stage, evaporite basins were created both on the African and Brazilian margins, but much of the faulting was diagonal to the main coastal trend. Although isostatic adjustments were mostly completed within 30 Myr, some lineaments are still somewhat unstable. The principal coasts however conform to classical eustatic standards (FAIRBRIDGE, 1976), though slightly modified by geoid change (MARTIN *et al.,* 1985).

The North Atlantic is more complicated as it opened in segments, the youngest being between Greenland and Norway, still active between N.E. Greenland and Svalbard. The center segment between North America and Western Europe/N.W. Africa began to open in the Triassic/earliest Jurassic. Numerous salt diapirs line the margin of Morocco. Coasts are fairly well stabilized and dominated by eustatic terracing, but in North America are warped due to the Laurentian postglacial recovery. To the south, on the West African side (Gulf of Guinea) a transtensional zone marks the gap where South America separated, but its coasts are well stabilized today. On the west, however, North and South America are separated with major strike-slips by the Caribbean blocks and the Antillean Arc. Here there is an east-facing, west-dipping subduction zone which, with a counterpart between South America and Antarctica (Scotia Arc). They present two anomalous re-entrants into the "Atlantic" realm. Another exceptional, but quite different feature is the Gulf of Mexico, the site of a major asteroid collision at the K/Te boundary, but earlier had opened, to become a classic "passive" margin yet highly dynamic in terms of salt diapirs and sedimentation.

The Indian Ocean, except for its Asiatic margins, is another example of the "Atlantic Type", except that it has been overwhelmingly dominated by the pull-apart between peninsular India (E. coast) and East Antarctica, followed by the astonishingly rapid drift of that subcontinent across the equator to collide with the Tibetan sector of Asia. Its geometry is thus "transtensional" and giant strike-slip faults mark the eastern edge of Madagascar, the Maldive "sliver", and the western edge of India. Another set of giant strike-slips (the Darling Fault, *etc.*) mark the Australian side. The Asiatic margin in contrast is marked by the sequential subductive loops of the Tethyan-Himalayan-Indonesian orogenic systems. Apart from these the coasts are mostly in the "passive" camp, dominated by its eustatic history (FAIRBRIDGE, 1961).

The Southern Ocean is bordered on the south by the East Antarctic continent, and separated from the Australian block by a distinctive pull-apart that began to open in about mid-Cenozoic time. The Australian margin is largely passive and marked by a eustatic history of "normal" characteristics although slightly modified in places by revival of some ancient fault systems (THOM, 1985).

(b) Collision and Intermediate-type (Back-Arc) Margins. These are the classical "Pacific-type" coasts, associated with major deep-sea trenches (5–10 km depths) and the now obsolescent "Andesite Line" (now known to be only broadly correct). The clearest example is that of South America parallel to the Andes, where the roughly east-moving oceanic plates meet the west-moving continental plate of South America in "standard" subduction zones. In the case of North America, however, there is no simple collision, because the plates are more fragmented and collisions are oblique except in the Cascade sector. Then farther south they are replaced by the San Andreas and Gulf of California transform systems. The entire western margin of North America is involved in the strike-slip systems of "exotic terranes" (or microcontinental slivers). For generalization purposes its geomorphology is lumped as "taphrogenetic" (FAIRBRIDGE, 1992).

These collision coasts of the eastern margins of the Pacific are replaced along the western edges by a series of "intermediate seas" with varied platelets, some oceanic and others "quasi-cratonic" (*i.e.* marked by subsidence). These basins of the western Pacific extend from the Aleutian region to the Sea of Okhotsk, Sea of Japan, Yellow Sea, China Sea, Philippine sea, South China Sea, Java Sea and others to the edge of the Australia Plate (linked to the Indian). They are mostly in the category of "back-arc basins", that is to say they lie west of the main subduction zone/island arcs of the western Pacific. Another group of the same sort are found in the S.W. Pacific, in the "Melanesian Borderland", a mixture of back-arc basins and pull-aparts that separate the ESE strike-slip lineaments of New Guinea in the north and the NNE lineaments of New Zealand and the Tonga belt.

Active subduction zones mark the borders of many of these basins, and geotectonics is clearly the dominant factor in coast development. The continental margins of Korea, China, Vietnam and Malaysia are marked by eustatic terraces in "normal" elevations. The same is true for many of the larger islands of Indonesia (KUENEN, 1933) but the smaller ones are prone to tectonic activity and may display multiple (uplift) coastal terraces. On the north shore of New Guinea at the Huon Peninsula there is a continuous "staircase" of emergent coral reefs that reach nearly 1000 m elevation and date back to the late Pleistocene, probably the world's most spectacular record of a plate-boundary uplift (BLOOM *et al.,* 1974; OTA, 1994).

Comparable to the Indonesian (East Indies) region is the Mediterranean, which embraces an extraordinary mix of continental plate boundary, subcontinental units, back-arc basins and Pacific-type subduction zones. It is, in fact, a midpoint in a complex zone of lineaments, recognized by CAREY (1981) as the "Tethyan Megashear". It can be traced northwestwards across the North Atlantic to the Canadian Arctic, and eastwards to the collision zone between India and Asia, and then ESE to the Indonesian complex and to the northern edge of the Melanesian Borderland where it dies out at the Pacific sea floor south of Samoa. The principal dynamics of the Tethyan Megashear was left-lateral (sinistral), accompanied by crustal torsion and large-scale rotation of major continental blocks. Counterclockwise rotation of the Iberian Peninsula was duplicated in the Balearic Islands and the Italian Peninsula. The Aegean Sea is a network of block-faults, of horsts and grabens. The Hellenic Arc is a subduction zone facing south, while the Magrebian Belt of Morocco-Algeria is one facing north. Remarkable uplift terraces are seen on Crete, Karpatos and Rhodos.

It is a curious historical paradox that many of the classical studies of eustatic oscillations were undertaken in the tectonically active parts of the Mediterranean. Nevertheless, many of the key measurements of eustatically monitored uplift were undertaken in Morocco and Algeria and some of the relatively passive coasts of Tunisia have provided a clear picture of the last 100,000 yr or so (PASKOFF and SANLAVILLE, 1983). One of the specific, but not always appreciated advantages of the Mediterranean lies in its abundance of written documentation (Greek and Latin), and its now well-dated artifacts of ancient human inhabitants. Even for pre-Last Glacial formations these data can be very helpful, in addition to isotopic dating.

In the Mediterranean region inheritance plays a major role. The cold cycles were marked by glaciers or periglacial sediments and landforms in the mountain belts (Alps, Dinarides, Pyrenees, Apennines, Betic, Atlas, Taurus and Lebanon ranges). Loess, that typical product of the glacial cycles, carried even to the Atlantic shores of Brittany and Portugal by easterlies driven by the adiabatic circulation from the Scandinavian ice. In the shore profiles the loess, together with cryogenic (frost) chips, colluvium, and grèzes litées or "stratified head", interfingered with the warm-water high-eustatic beach facies. During the glacials the prevailing westerlies for their part dominated the African shores and deposited "lee-desert" red dusts in Sinai, Palestine, Israel and Lebanon, which interfinger with the interglacial eustatic highs.

(c) Isostatic Readjustments. Although these infer long-term motions, they can in fact be treated in an actualistic framework and in many cases can be measured by geophysical procedures, ranging from tide-gauge analysis to satellite monitoring. As distinct from plate-tectonic dynamics (treated above, in sections "a" and "b") which are largely *horizontal*, these isostatic processes are largely *vertical* in their effects. Three categories may be recognized:

(i) Geotectonic or tectono-eustatic vertical motions that are associated with plate rupture, rifting and the initiation of sea-floor spreading. The latter is an inference, but reliably based on the evidence of many examples. Active rifting is associated with an up-to ten-fold increase in measured heat flow. General uplift is therefore to be expected. Uplifted coastlines are a dramatic feature of active plate boundaries in the extensional or transtensional categories. Following the rupture phase, with its igneous activity, there is a cooling phase and general subsidence, with block faulting and tilting. Coasts display drowning and, in warm latitudes, barrier reefs and atolls. Recent or contemporary activity is termed "neotectonics" and is the subject of a permanent study commission of the International Union for Quaternary Research (Chairman N.A. Mörner).

(ii) Glacio-isostatic crustal response that follows glacial loading and unloading, together with marginal bulge effect (DALY, 1934). The uplift with unloading is extremely rapid and in some areas (*e.g.* maritime Canada) outlying parts of the ice sheet developed a reverse flow, as seen from the striation directions (from east to west). The initial retreat of the ice front is shown by successive terminal moraines at 50–100 m intervals per year both in Scandinavia and Quebec (termed "de Geer moraines" after their discoverer). The rapid decompression of hard crystalline rocks (as in Sweden and Quebec) caused rock bursts that, within the year of release, threw up blocks of bedrock up to 2–3 m across, leaving the striated surface on one side or the other (MÖRNER, *pers. comm.*).

In the central part of the Laurentian ice sheet, the uplift (over 300 m) is shown by dated shorelines to over 8300 B.P. (FAIRBRIDGE and HILLAIRE-MARCEL, 1977). In central Sweden (Doksta) it is over 280 m. Present-day shoreline emergence in the eastern Hudson Bay exceeds 5 mm/yr, but in the Gulf of Bothnia approaches 8–9 mm/yr.

The marginal bulge may have been over 30 m high at one stage but has collapsed exponentially, rapidly at first, but probably no longer active today.

(iii) Hydroisostatic crustal response to water loading. The melting of the great ice sheets (mainly in North America and northern Europe) began about 15,000 yr ago, and initiated an increase in the load of water on the world's sea floors, hand-in-hand with the removal of the ice loading on the continents. The latter's distribution was highly asymmetric (maximum about 70°W and 60°N), so that a complex geodetic correction was needed to bring about the present equilibrium. It involved fundamental assumptions about the strength of the mantle, but difficulties remain, involving among other things, the homogeneity of the mantle, so that this problem is an ongoing area of study in geophysics.

Calculations of the theoretical response generated a global map with an expected anomaly of over 3 m in a broad band running south of the equator at 70°W to north of it about 110°E. There is indeed widespread evidence throughout this belt for mid-Holocene sea levels at about 3 m above present. The specialists involved, however, conveniently ignore the vast accumulation of paleoclimatic data (see any issue of *The Holocene*, the principal journal in this area) that display repeated fluctuations in the range of 3 m above AND BELOW present sea level, at periods of the order of 500–1500 yr. "Standard" eustatic curves have been prepared for such disparate regions as Brittany (N.W. France), China, S.W. Australia and several parts of North and South America (TERS, 1987; FAIRBRIDGE, 1992).

The Atlantic coast of South America has provided, perhaps, the strongest support for this hypothesis, because there is a clear rise in the level of identical coastal units from about 30°S to the equator, from about 3 to 5 m (SUGUIO *et al.*, pers. comm.). This investigation deserves serious notice, and needs to be replicated in other sectors of the globe.

The conclusion reached among many coastal specialists is that the hydro-isostatic hypothesis is probably well justified in theory but that its field demonstration remains with a "hung jury" (see discussion under "d", below).

(d) Geoidal Readjustments. These are geophysical responses to a large array of interacting systems, the signals from which are extremely difficult to separate out. They include the Earth's spin rate, mass loading, atmospheric pressure, winds and currents. All these factors fall under the general title of "CLIMATE", which remains one of science's totally unsolved problems.

(e) **Steric Changes.** These are the volumetric responses to changes in thermal and salinity factors. Although, in principle, the problem is well understood, its regional application is extremely difficult, because the oceanic-atmospheric regimes are continuously interactive and for long-term studies require the use of notoriously fickle proxies.

(f) **Eustatic Changes.** Although the concept goes back to the 1840's and the Glacial Theory, and the term "eustatic" was introduced by SUESS (1888) to cover basin-filling, and although the writer reviewed the field (FAIRBRIDGE, 1961), the problems persist. To simplify the terminology the following have been adopted:

(i) Tectono-eustatic, for uniform changes of sea-level that are forced by tectonic changes in the shape of the container (visualized as a plastic cup, filled with a liquid. If squeezed, the ccontents will spill over). Thus, without change in the volume of ocean water, the shores will undergo transgressions if the ocean floor expands and rises, as during accelerated sea-floor spreading or extensive submarine volcanism. The sudden opening of a deep-sea trench, in a subduction zone, will cause a rapid fall of sea level and general regression. A giant waterfall at the Bosporus during the early Holocene, or near Gibraltar at the end of the Messinian stage, would equally well lead to negative eustasy. The "Vail curve" of sequence-eustatic behavior indicates strongly asymmetric behavior, rapid fall, followed by slow build-up.

(ii) Sedimento-eustasy. This was conceived by Suess as a mechanism that involved the periodic filling of the Mediterranean basins with sediment, interrupted by periodic escape to the world ocean. At best it would have been a slow process, and one that hardly needs consideration in an actualistic framework. Nevertheless, some of the ancient shorelines of the "Paratethys" basins are still visible, in fact beautifully preserved, in southern Germany and in Austria, dated about 10 Myr.

(iii) Glacio-eustasy was the first of the three to be recognized, as a logical consequence of the Glacial Theory (MACLAREN, 1842), and followed soon after (CHAMBERS, 1848) by an excellent book describing shorelines in the former glaciated regions of Quebec and N.W. Europe.

The presence of "raised beaches" in many parts of Britain and Scandinavia drew attention to the isostatic uplift, but their remarkable episodicity long remained enigmatic. The problem was their dating. In Sweden it was achieved using the varve-counting system of DE GEER (1912), but elsewhere the latter was not well received and had to await an isotopic (C-14) chronology in the 1950's.

Far away from the glaciated regions, came the first general recognition of a mid-Holocene sea level that seemed to match the very clearly demonstrated warm phase or phases in North America and northern Europe (the so-called "hypsithermal" of North America; the "Atlantic biozone" of Europe). Using relative geomorphology and degree of weathering, DALY (1934) concluded there was a general high sea level of 3–5 m, based initially on his observations in Samoa, and already by 1920 he was writing about "a recent worldwide sinking of ocean level". Shortly after, the Dutch scientific expedition to the East Indies on the ship *Snellius* allowed KUENEN (1933, 1950) to examine its coasts on innumerable islands and reefs, and reached the same conclusion. During WWII in the S.W. Pacific and later in Australia, the writer (FAIRBRIDGE, 1950, 1961) recognized there was not a single high sea level, but multiple oscillations (labeled by critics, in derision, the "Fairbridge Curve"). Simple errors are explained by NUNN (1995).

DALY and KUENEN offered no theoretical justification for it, but Fairbridge, with the benefit of Swedish varve dates and, after 1950, radiocarbon analyses, saw one-to-one correlations with the pollen/varve/sea level chronology in Scandinavia (synthesized by Mörner, 1969 and summarized by FAIRBRIDGE, 1987). Sea-level fluctuation thus had a direct link to climate fluctuations, and the amplitude and importance of the latter have grown progressively into the 21st century. As to climate, it had generally been assumed by establishment meteorology to be essentially uniform, but by the early 21st century, a growing body of opinion was beginning to recognize (a) that climate (within recognized constraints) was a natural fluctuation, and, following the evidence of oil geologists (the "Vail Curve"), could be traced back at least 4.6 $\times 10^8$ yr. And (b) that climate was forced by the extraterrestrial orbital controls of the Moon and Sun (as predicted by Croll and Milankovitch, and developed by ZEUNER, 1959). Furthermore there is increasing evidence of a factor (c) that the Sun's radiations were modulated by angular momentum forcing due to planetary orbital controls, that those radiations were linked to terrestrial climate (FAIRBRIDGE and SANDERS, 1987; FAIRBRIDGE, 2003).

(g) **Artificial or Man-made Coasts.** It is appropriate to close this review with a recognition that almost all coasts are in some way or other being constructed or modified by human actions. Some modifications go back more than three millennia, to the Bronze Age, and the strenuous dike-building that began in Roman times, see KING (1959/'72), ROHDE (1978) and others. Now, by the 21st century dikes and tide-controls are facts of life. Desalinization, fish farms and other aspects of marine exploitation are world-wide. However, with all the human activities involved, a word of warning is appropriate. Hazards can be mitigated by knowledge of the past.

SUMMARY

Coastal classification has been made needlessly complicated in the past by failure to concentrate on directly observable attributes and by the need to constrain deductive reasoning to the known framework of established geologic and palaeoclimatic history. Here, we recognize:

(1) *COASTAL MATERIAL*
   (a) *Soft, Weakly Consolidated and Easily Erodable*; relative solubility (in seawater and rainwater). Creating mudflats, beaches, bluffs and low cliffs.

(i) Relatively insoluble: detrital products such as mud, silt, sand, gravel, boulders (loose).
(ii) Relatively soluble: reef limestones; bioclastic carbonate debris (foraminifera, calcareous algae, mollusca, coral). Beachrock and eolianite (calcarenitic cements often weak and temporary).
(iii) Pre-weathered hard rocks: "grusification" or reduction in hot-wet tropics to grus or crumble, leaving unweathered corestones within easily eroded saprolite.
(iv) Hard concretions (such as cherts or "flints") released by differential wave erosion to create cobble or "shingle" beaches.
(v) Volcanic materials (interlayered lavas, pumice, ash or lapilli), reduced by wave action to boulders, black sands, *etc.*

(b) *Hard Rock and Cliffed Coasts*
(i) Longevity of hard-rock coasts;
(ii) Anomalous hard-rock boulders due to diachronous sea-ice transport;
(iii) Landsliding, with rotational slip;
(iv) Landsliding on volcanic cones, with control of atoll form;
(v) Fault-controlled cliffs (taphrogenic and plate-margin);
(vi) Fossil or "Dead" Cliffs (Falaise mortes Fr.)

(2) *PHYSICAL SETTING*
(a) Latitude (Solar Radiation, Seasonality and Weathering Potential.
(b) Climate (Prevailing Winds, Storms, Sea Ice).
(c) Fetch (Open water for wave approach.)
(d) Offshore Bathymetry (Wave Regime and Longshore Currents).
(e) Tides (diurnal, seasonal and 18.6 yr nodal).
(f) Tsunami Potential (volcanoes, submarine slides).
(g) Homogeneity (beach extent, headland frequency).

(3) *EROSIVE AGENCIES*
(a) Physical Agencies
(i) Abrasion
(ii) Hydraulic; impact
(iii) Wind and tide-driven ice floes and icebergs
(iv) Ice-foot ("glaciel")

(b) Chemical Agencies
(H^2O, CO^2, CH^4)
(i) Subaerial weathering preparation
(Mainly feldspars and micas)
(ii) Carbonate rocks
(iii) Volcanic rocks

(c) Biological Agencies
(i) Mangrove and salt marsh
(ii) Limestone and Uplifted Coral Reef Undercuts, populated by borers and scrapers.
(iii) Barnacles, footing solution.
(iv) Echinoids and boring molluscs (*Lithophagus* spp.).
(v) Kelp and other algal holdfasts.

(4) *HISTORY: GEOTECTONIC, ISOSTATIC, GEOIDAL AND EUSTATIC*
(a) Extensional, Passive, Trailing Edge or Pull-apart Plate Margins.
(b) Collision or Intermediate-type (Back-Arc) Margins.
(c) Isostatic Readjustments, of three types:
(i) Geotectonic, vertical motions associated with plate rupture.
(ii) Glacio-isostatic, crustal response to glacial loading and unloading (including marginal bulge effect).
(iii) Hydroisostatic crustal response to water loading.
(d) Geoidal Readjustment to changes in the Earth's spin-rate, mass loading, atmospheric pressure, winds and currents.
(e) Steric changes, volumetric response to thermal and salinity changes.
(f) Eustatic changes:
(i) Tectono-eustatic
(ii) Sedimento-eustatic
(iii) Glacio-eustatic
(g) Artificial or man-made coasts.

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